



Traveler

Trustworthy Autonomy

October 21st, 2016

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Principle Investigator Automatic Systems
Armstrong Flight Research Center

Research Timeline



1980

2000

2010

2016

Automated Maneuvering Attack System (AMAS)



Automation Research

AFTI/F-16

Advanced Fighter Technology Integration



AFTI & ACAT/F-16

Automated Collision Avoidance Technology

Automated Collision Avoidance

Air



Ground



Integrated

Dedicated Safety Work

Ground Collision Avoidance

GA

Small UAS



Quad-Rotor



Platform Diversity

SUAV/iGCAS/SR22

Improved Collision Avoidance System



Avoid Collisions



**Do Not
Impede
the Pilot**



SULLY2 HUD

BFM-9

5 May 16

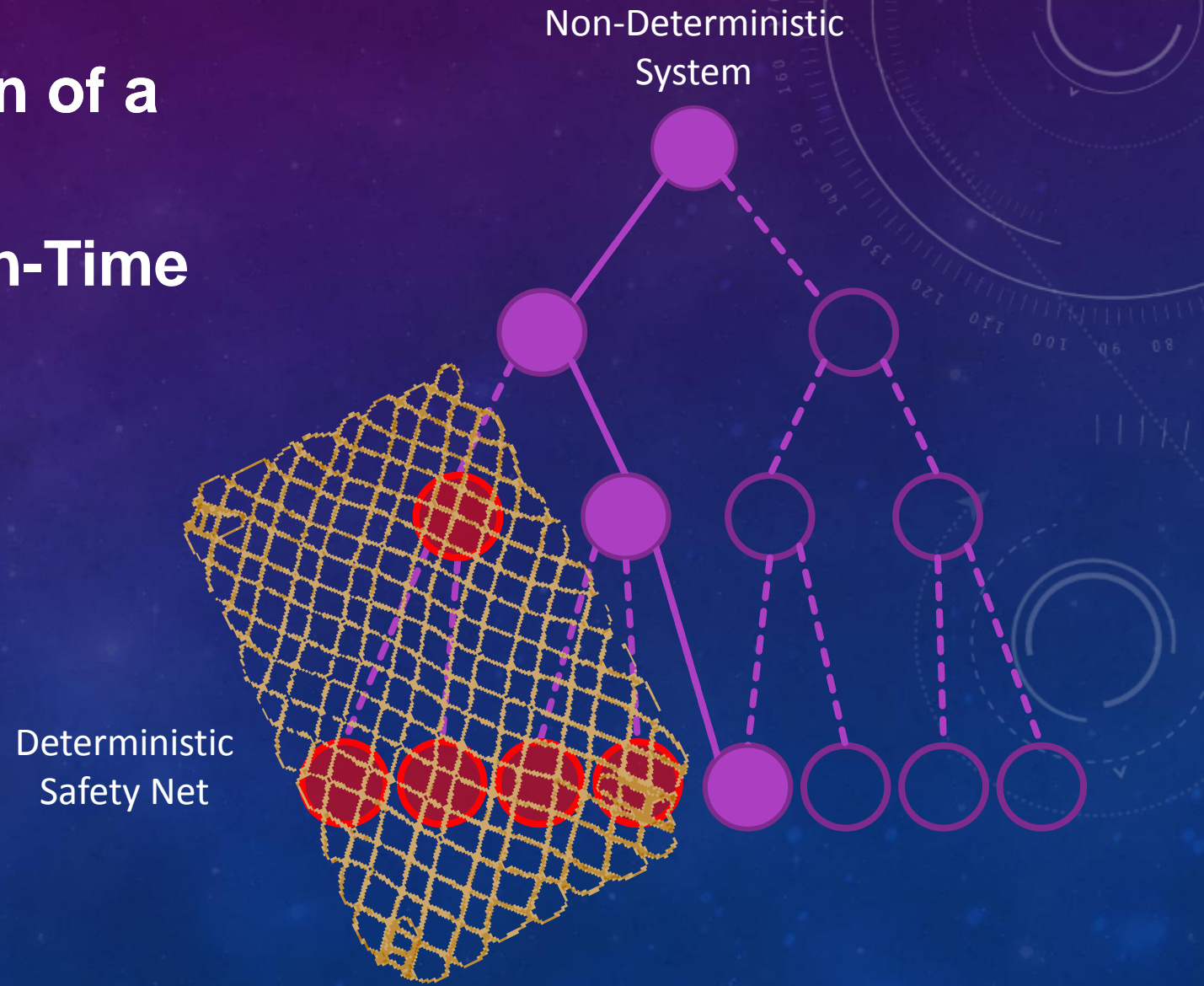
sUAV

SR22 Hardware in the Loop Sim

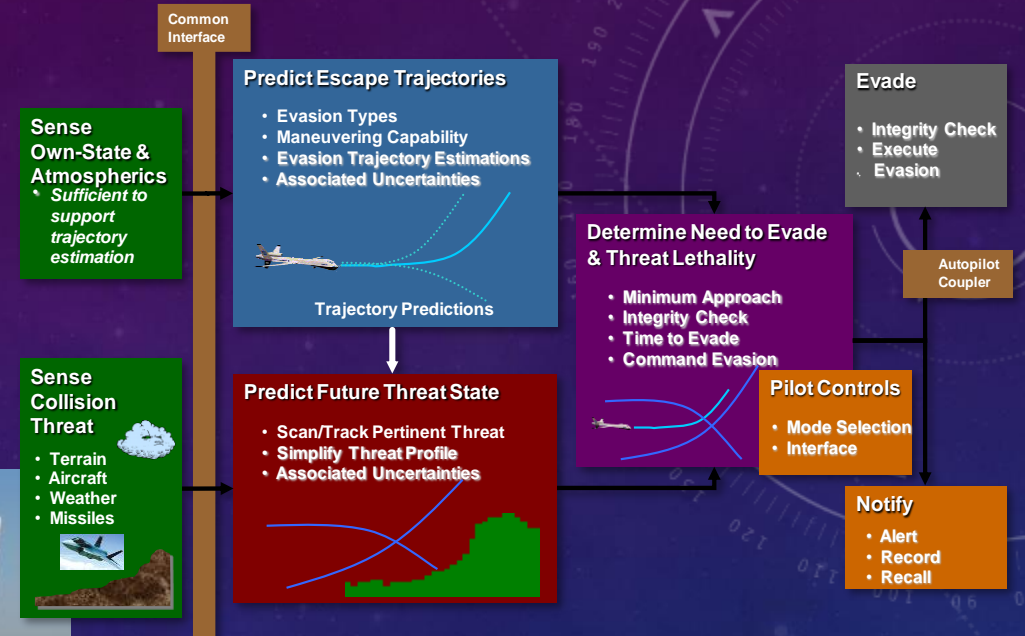
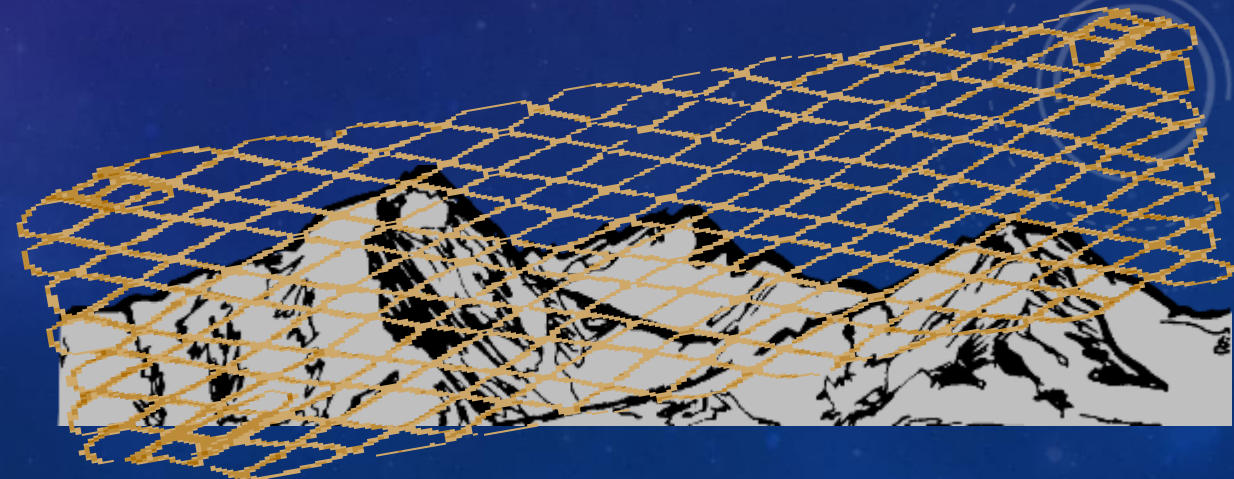


The Challenge of Autonomy

- **Verification & Certification of a Complex System**
- **A Possible Solution – Run-Time Assurance (RTA)**



Safety Systems



Multi-Monitor RTA



FAA/ASTM Collaboration

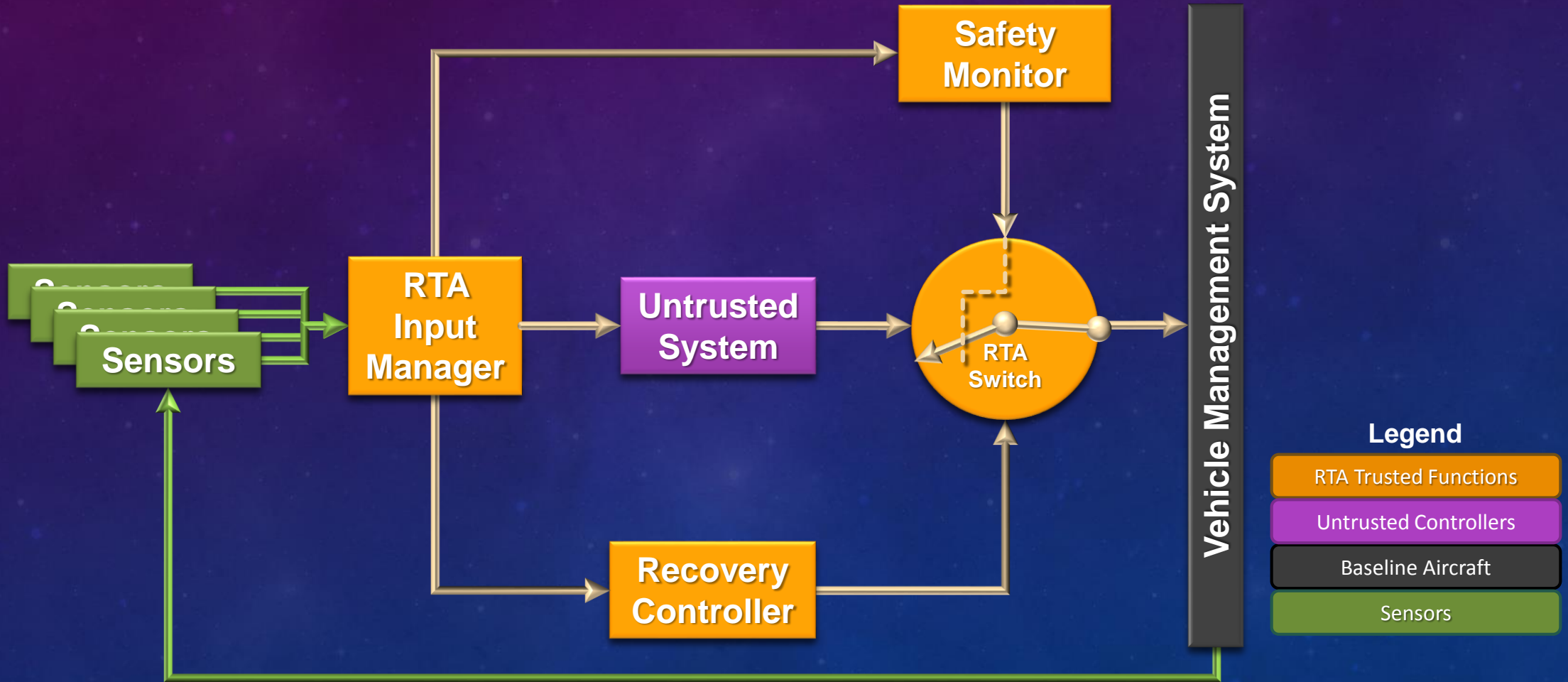
- **ASTM Committee WK53403**
 - Develop a standard practice that safely bounds the flight behavior of autonomous UAS.
 - Originated from our collaboration with them regarding Auto GCAS and integrity management work on early autonomy concepts
 - FAA has asked up to support the ASTM by sharing our techniques, practices and lessons learned as we develop EVAA
 - Dec 16 Draft for Public Review
 - Feb 17 Published



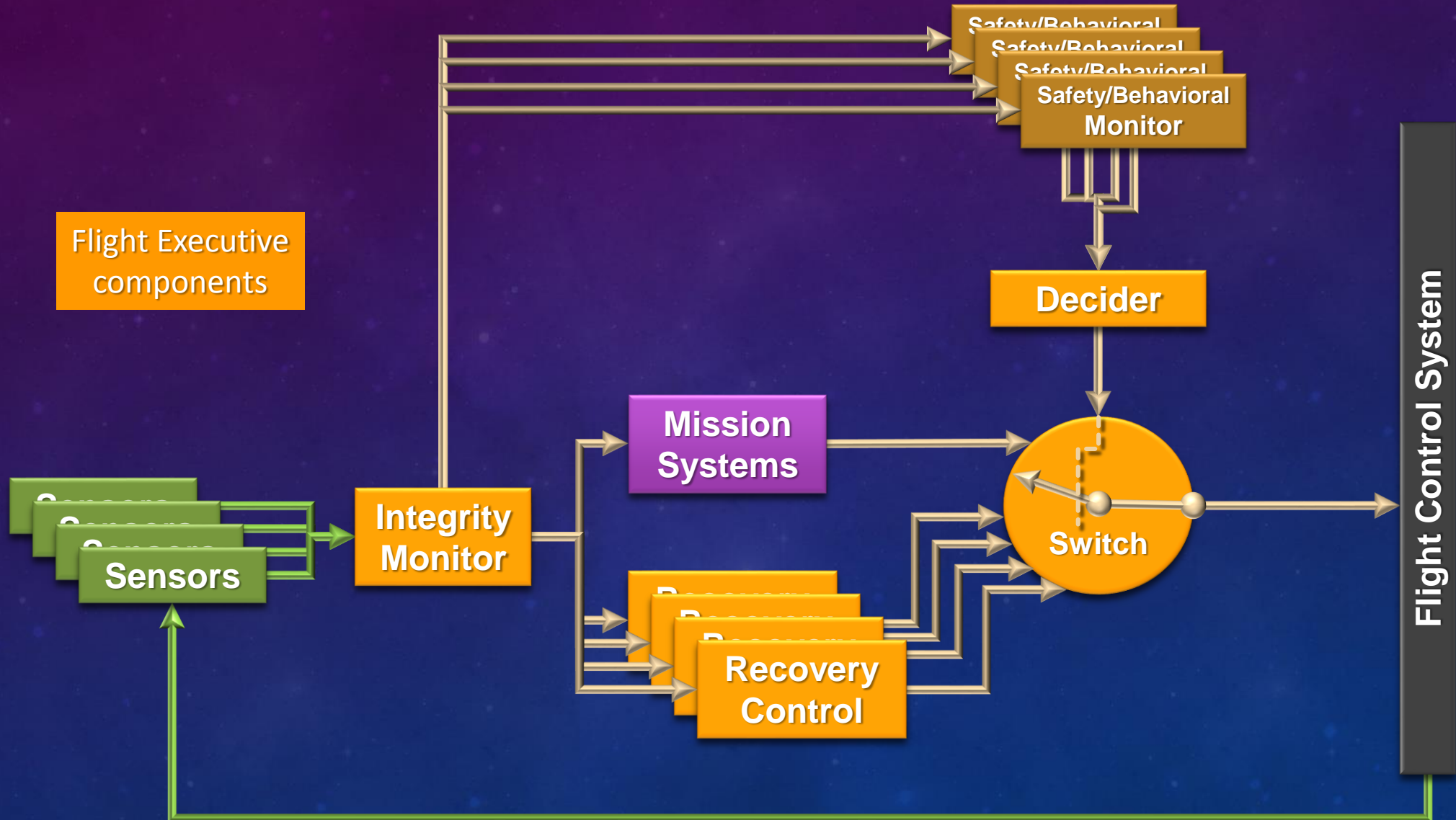
RTA Framework

ASTM WK53403

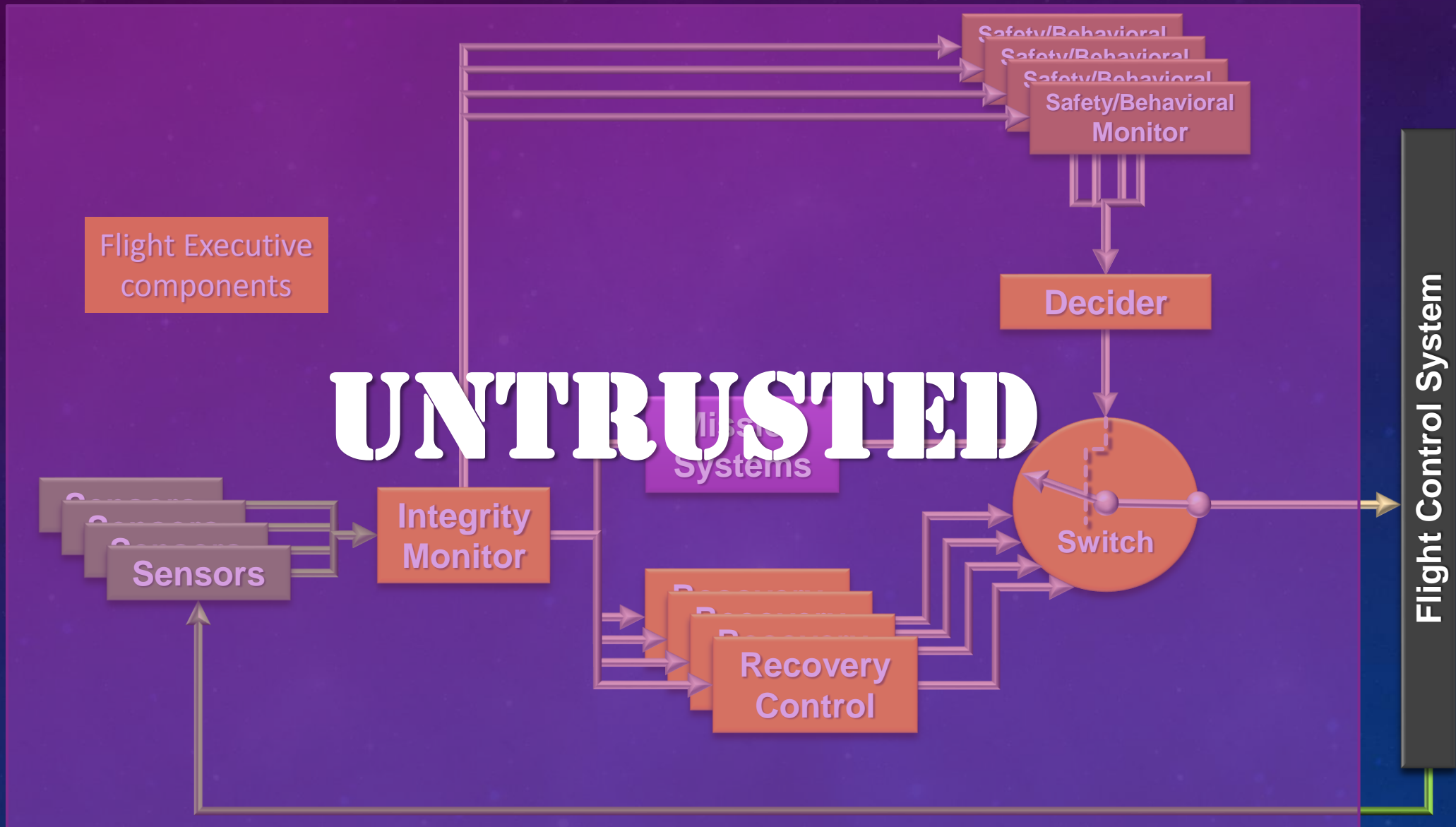
RTA Framework



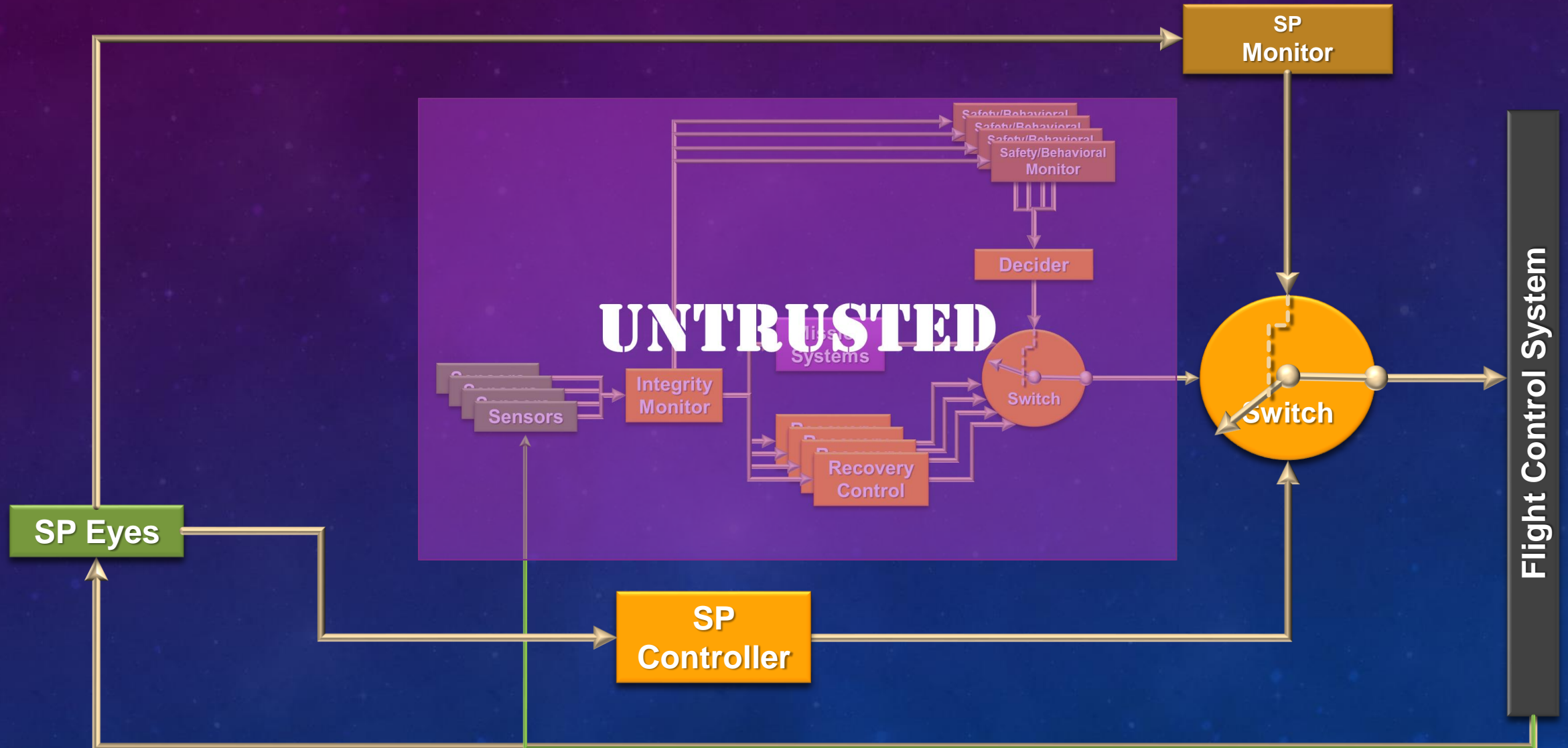
Multi-Monitor RTA Framework



Multi-Monitor RTA Framework

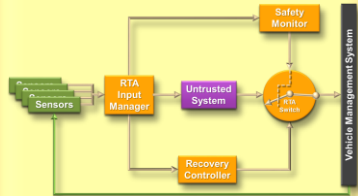


Multi-Monitor RTA Framework



Communicate

Behavioral Control Level



~Controllers

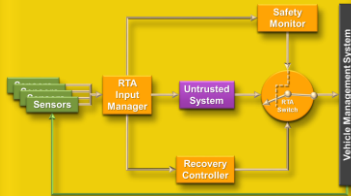
- Avoidance Maneuvers
 - Rate/Att. Capture
 - Waypoint Following
 - Altitude Capture
- Aircraft Lighting

Monitors

- Well Clear
 - Well Clear/Sep. Assur.
 - Rules of flight
- Airspace Boundaries
- Personal Space
- Privacy Rights
- Property
 - Property Rights

Aviate & Navigate

Mission Interoperability Control Level



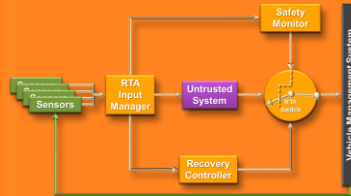
Controllers

- ATC
- UTM

Monitors

- Communications

Aviate Control Level



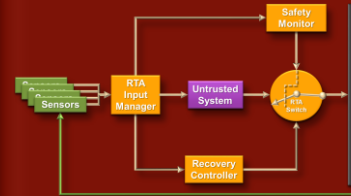
Controllers

- Avoidance Maneuvers
 - Rate/Att. Capture
 - Waypoint Following
 - Altitude Capture

Monitors

- Collision Avoidance
 - Ground
 - Obstacle
 - Air Traffic
 - People & Property
- Weather Avoidance
- Person Avoidance
- Population Avoidance

Emergency / Degraded Control Level



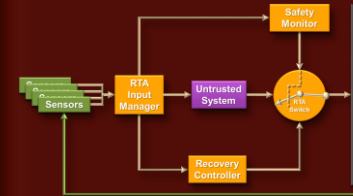
Controllers

- Forced Landing
- Where to Land
- LoC Prevention
- LoC Recovery

Monitors

- LOC
- Power Plant

Outer-Loop Control Level



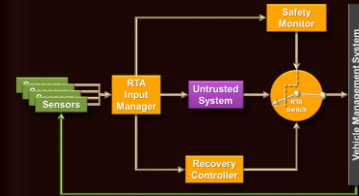
Controllers

- Pitch Autopilot
- Roll Autopilot
- Speed Autopilot

Monitors

- OLIV
 - A/C State
- Dynamic Consistency
 - Is this OLIV?

Inner-Loop Control Level



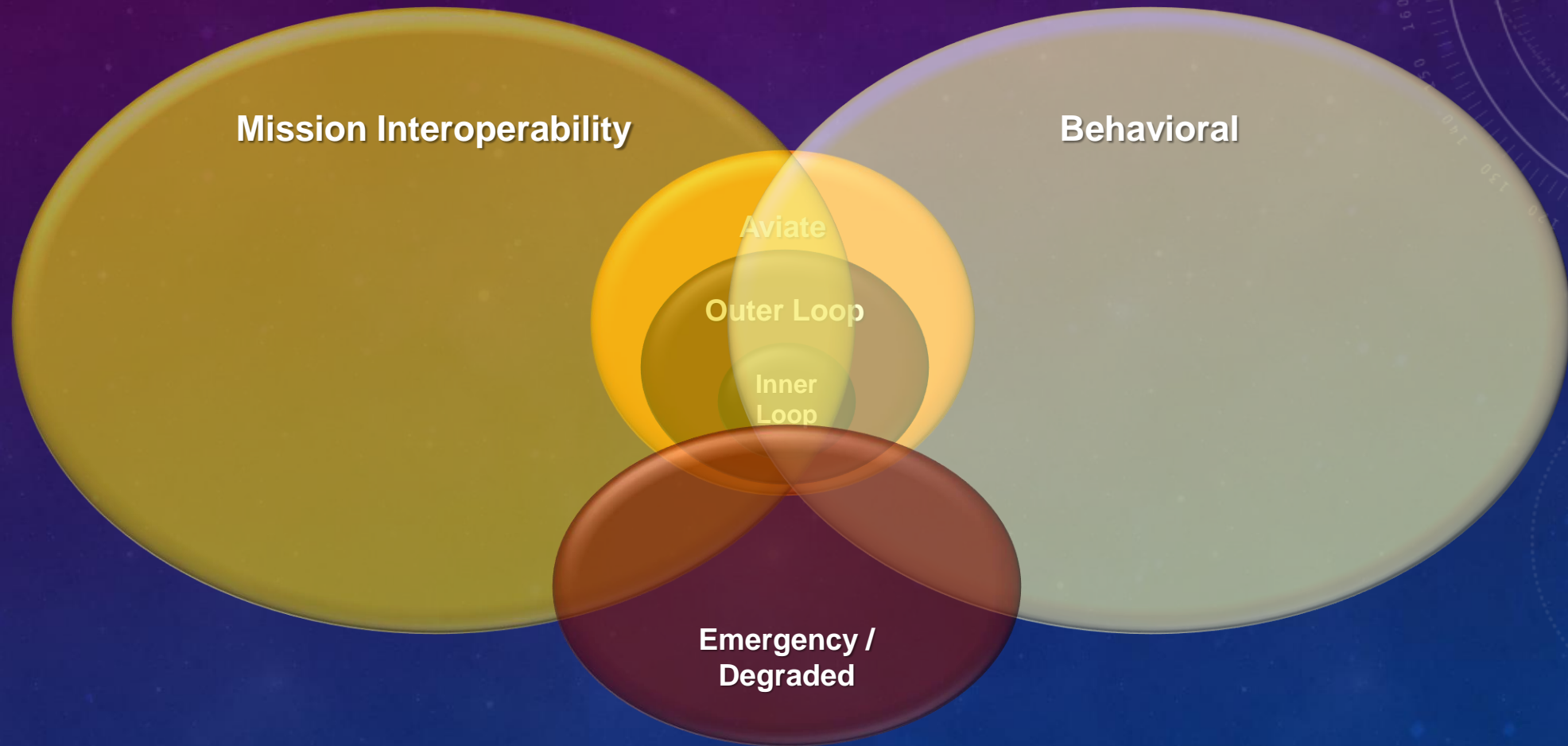
Controllers

- Stability & Control
- Structural Limiting
- Envelope Protection

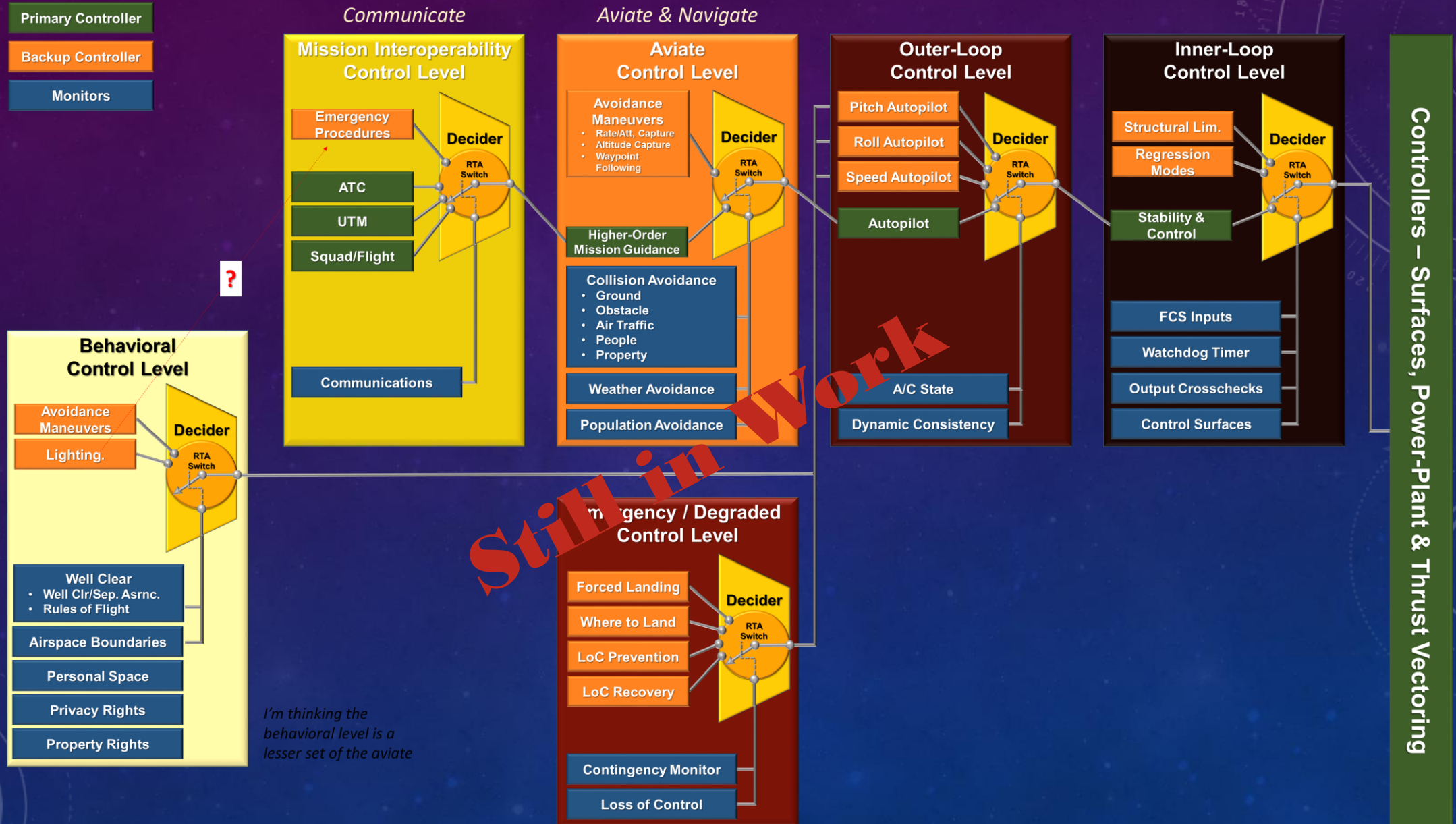
Monitors

- Sensors
 - Air Data
 - Accelerometers
 - Gyros
 - Angle of Attack
 - Sideslip
- FCS
 - Watchdog Timer
 - Output Crosscheck
 - Control Surfaces

Interlinked RTA Control Framework

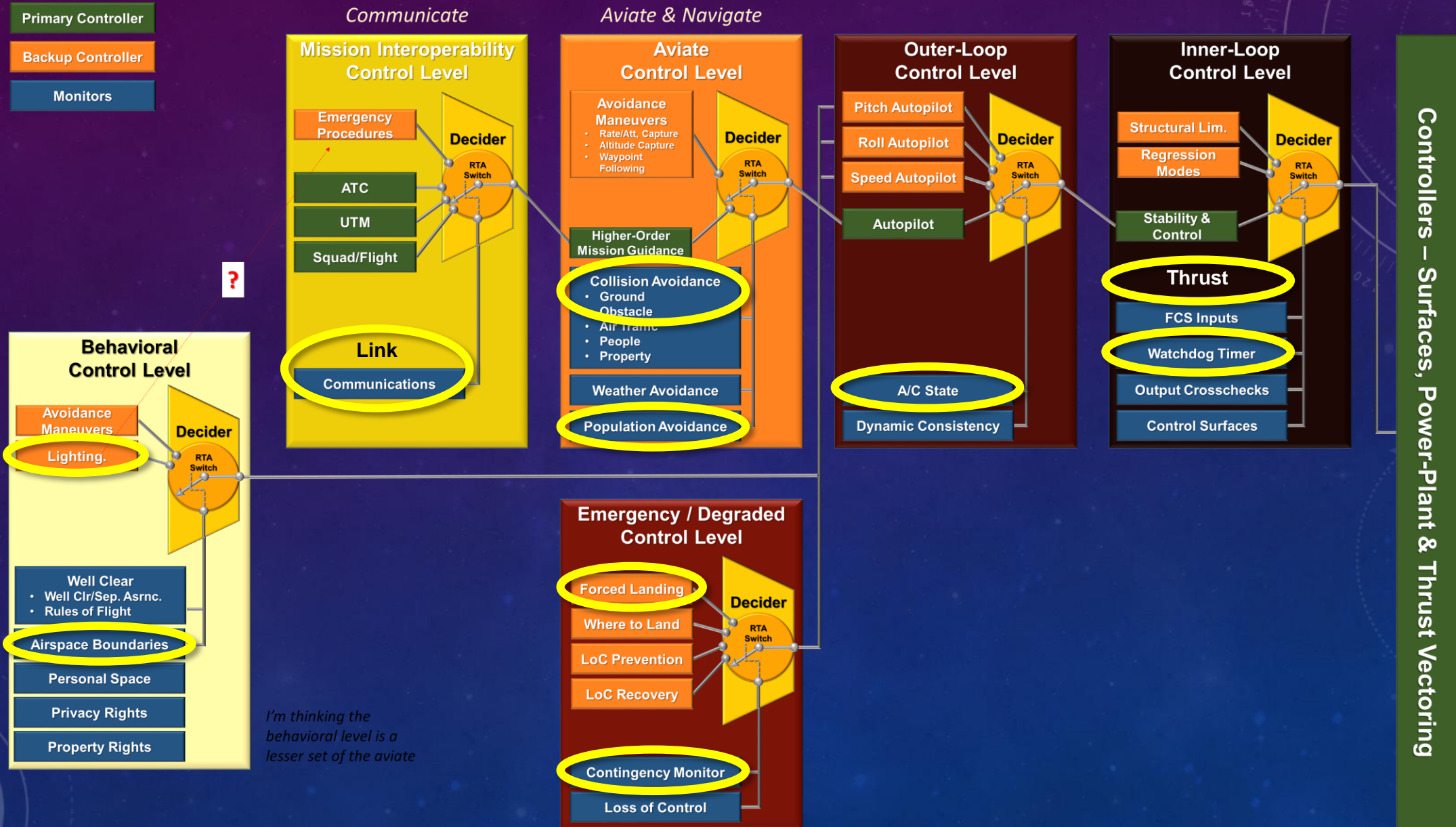


Multi-Monitor/Multi-Layered RTA



Multi-Monitor/Multi-Layered Comprehensive RTA

Phase 1 – All data base driven



QUESTIONS



The Big Picture - Traveler

Trustworthy Autonomy

Certification

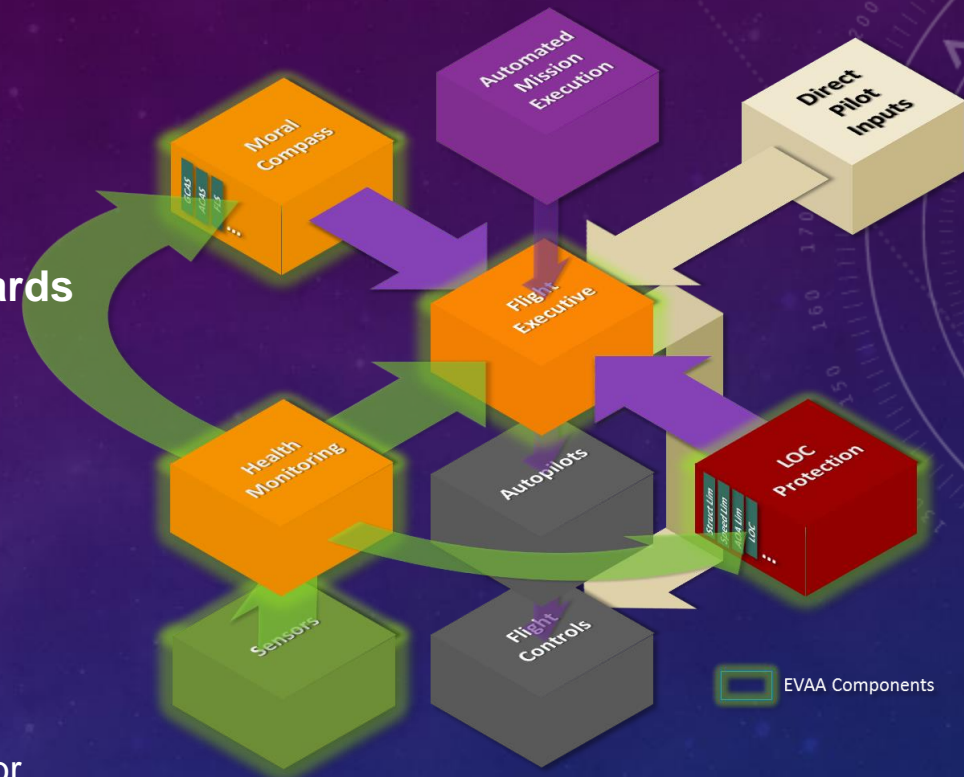
- Developing research findings to inform standards development for certifiable autonomy
- Collaborating with ASTM Working Group on autonomy certification guidelines
- FAA Collaboration and Interest

Expandable Variable-Autonomy Architecture (*EVAA*)

- **Stretching the paradigm of autonomy**
 - Determinist Rulesets Bounding Autonomous Behavior
 - Risk-Based Decision Making
- **A process enabling certification**
 - Software Architecture/Framework
 - Test Approach
- **Scalable autonomy**
 - Pilot-in-the-Loop to “Fully Autonomous”

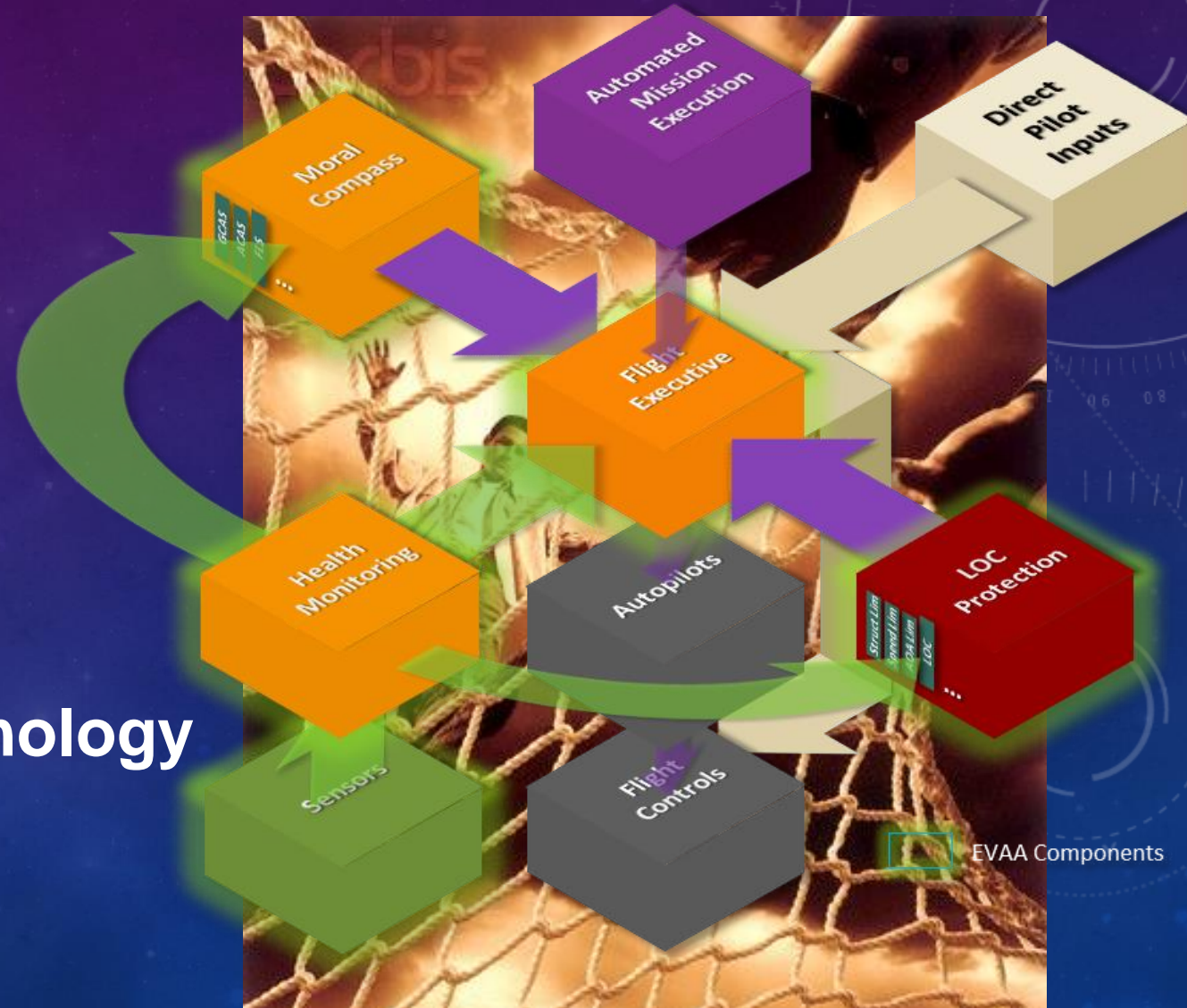
Low Altitude Small UAS Test Ranges (*LASUTR*)

- A tool for certification
- High-risk integrated research



Expandable Variable Autonomy Architecture (EVAA)

- **A Software Framework**
 - A Federated Architecture
 - Safety Systems
 - 1
 - 2
 - 3...
 - Flight Executive
 - Software Structure & Techniques
- **Classical & Non-Classical Verification Methods**
- **Safety Evaluation of the Technology**
 - Targeted at Flight Demonstrations
 - Social Interaction



Armstrong's Traveler Effort

- **Goal: Trustworthy Autonomy**
 - BVLOS to and from uncontrolled areas
 - 400 feet to Surface
 - Any Number of Aircraft per Operator
- **NASA Funded Effort**
 - Leverages a 30 year development of autonomy from DoD & NASA
 - TRL 3 to 5
 - Local Armstrong Directed Objectives
 - Supporting formulation of TACP Autonomous Systems start in 2018
- **Primarily Software Approach and Process Development**
 - Platform ~Agnostic
 - Mission ~Agnostic
 - Sensor ~Agnostic
- **Flight Development and Evaluation in Support of ASTM Regulatory Development**
 - Target Demos to Make an Airworthiness Case to
 - Possible High-Visibility Demo in Spring of 2017
 - Second Demo possible in 2018



LASUTR

How is LASUTR different from FAA Test Sites?

Agile/Flexible

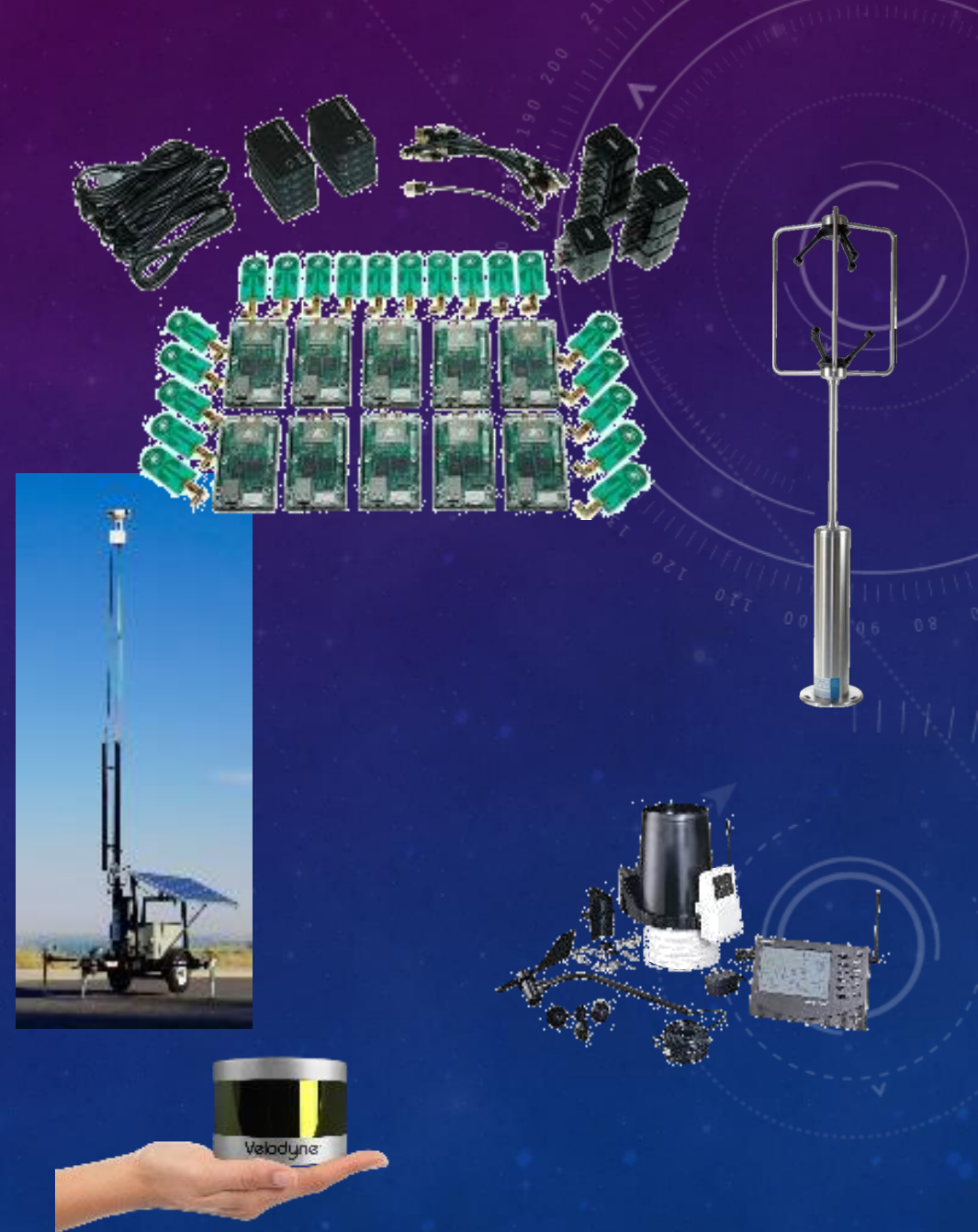
- No COA allows for rapid changes based on evolving requirements

Interoperability

- Ability to test multiple aircraft/concept in an integrated manner

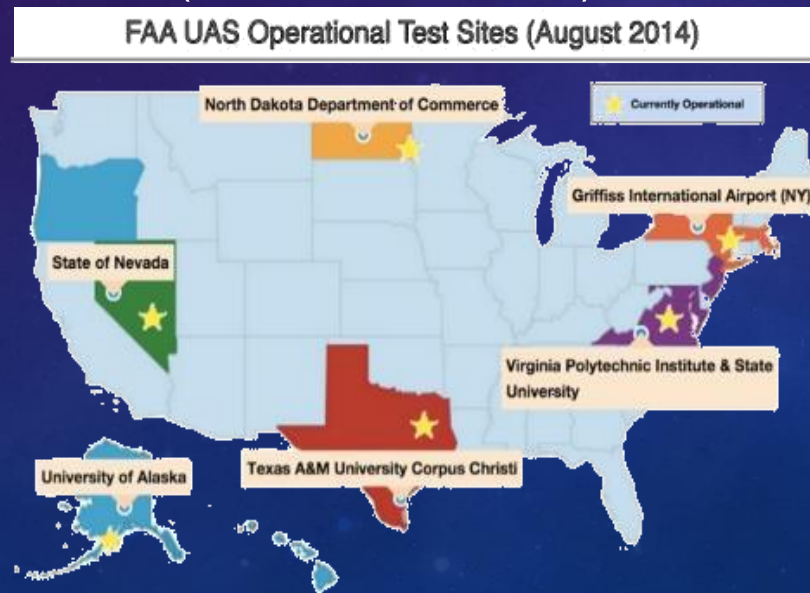
High-Risk Testing for New Concepts

- BVLOS
- Autonomy
- Night operations
- Controlled “risk” including controlled “crashes” without FAA accident notification requirements



LASUTR and FAA Test Site Collaboration Flow

- High-risk research conducted at LASUTR
- This generates research findings to help formulate testing requirements
- Research findings are shared with community of interest (FAA, Test Sites, industry, academia)
- FAA generates testing requirements for Test Sites (and other entities)



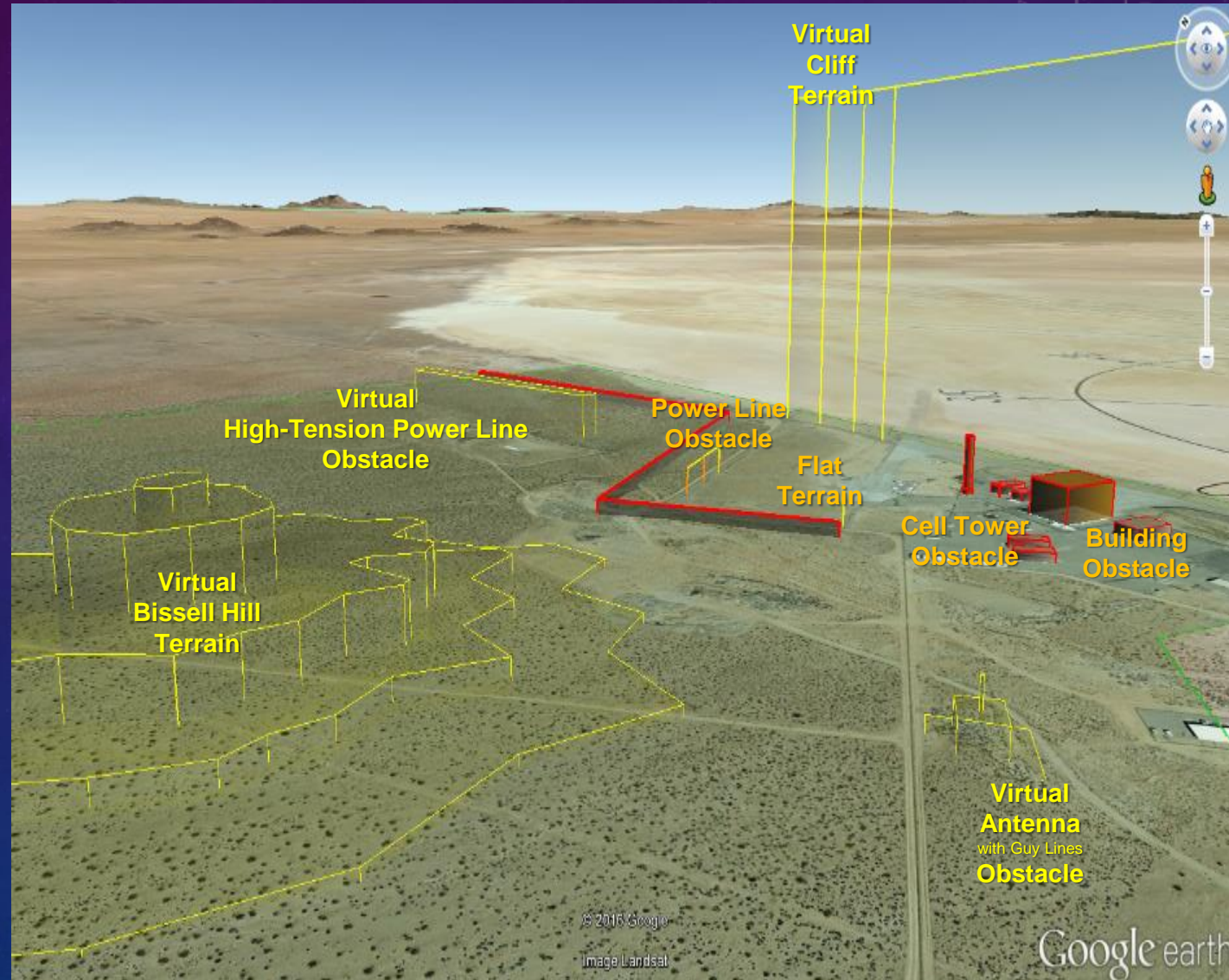
NASA South – Range for High-Risk Research

- **Terrain**

- Flat
- Virtual Cliff
- Virtual Hill
- 4 mile loop
 - Much longer at other LASUTR sites

- **Obstacles**

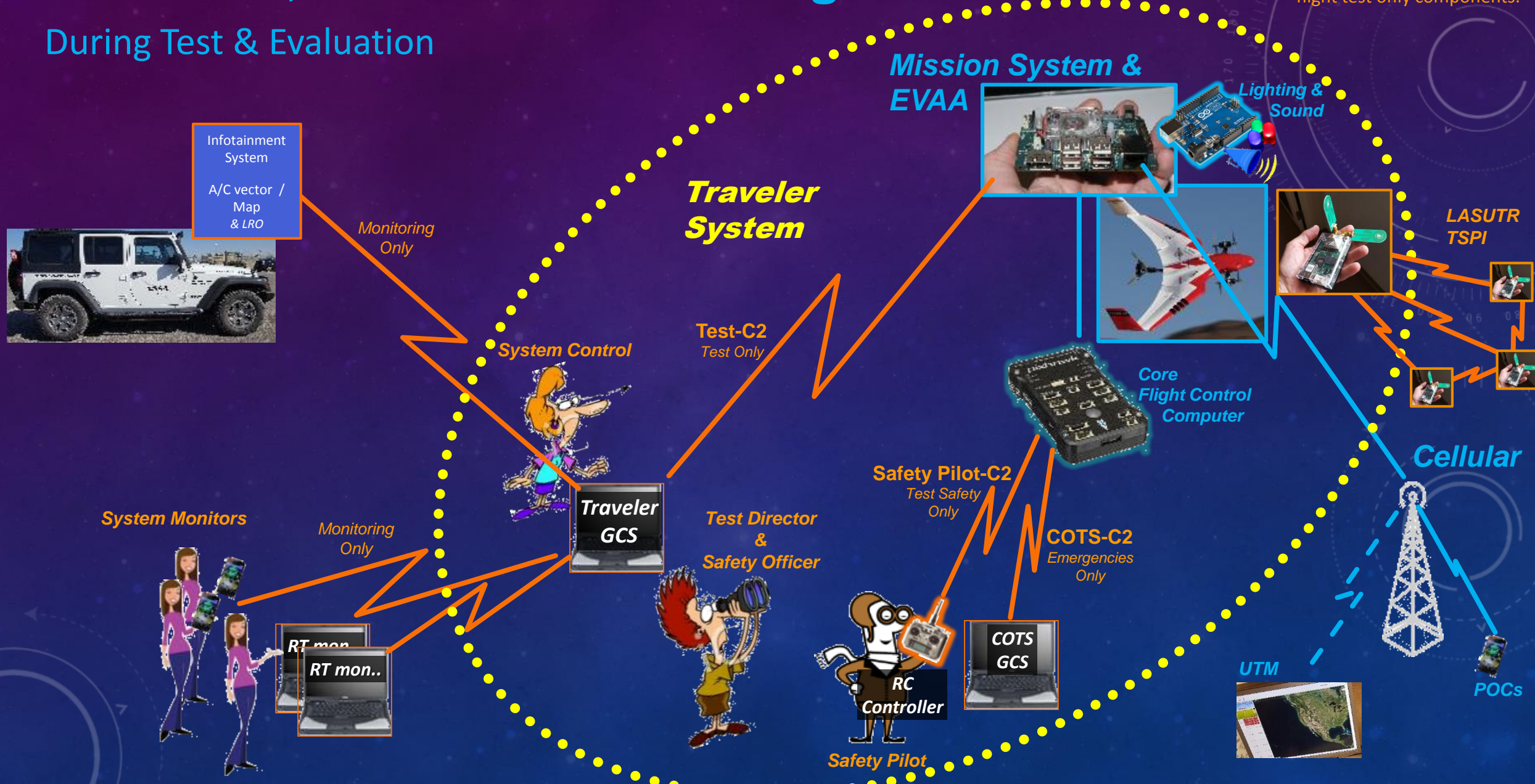
- Cell Tower
- Shuttle Hangar
- Light Poles
- Power Lines
- Virtual High-Tension Power Line
- Virtual Power Lines
- Virtual Antenna with Guy Lines
- Trees



Command, Control & Monitoring Architecture

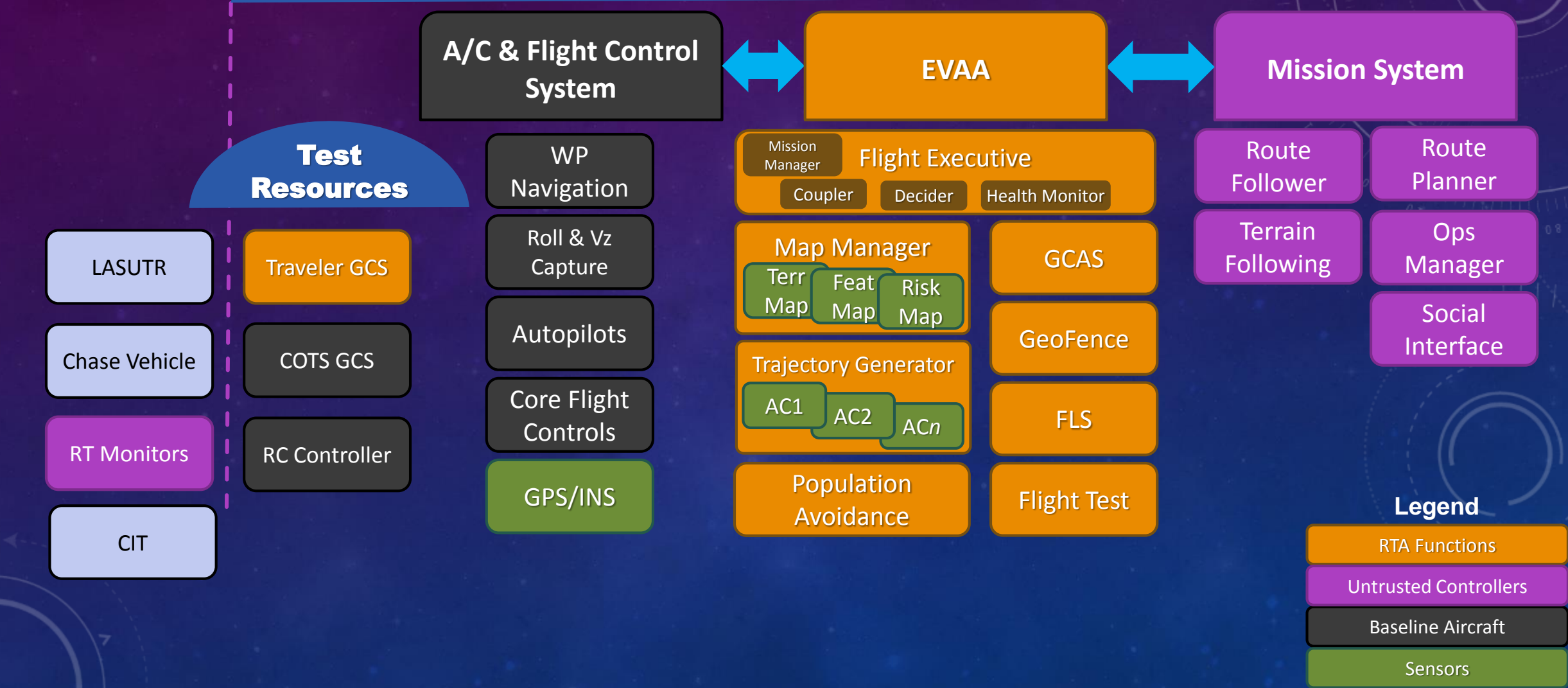
During Test & Evaluation

Blue text & lines indicate the core autonomous system.
Orange text & lines indicate flight test only components.



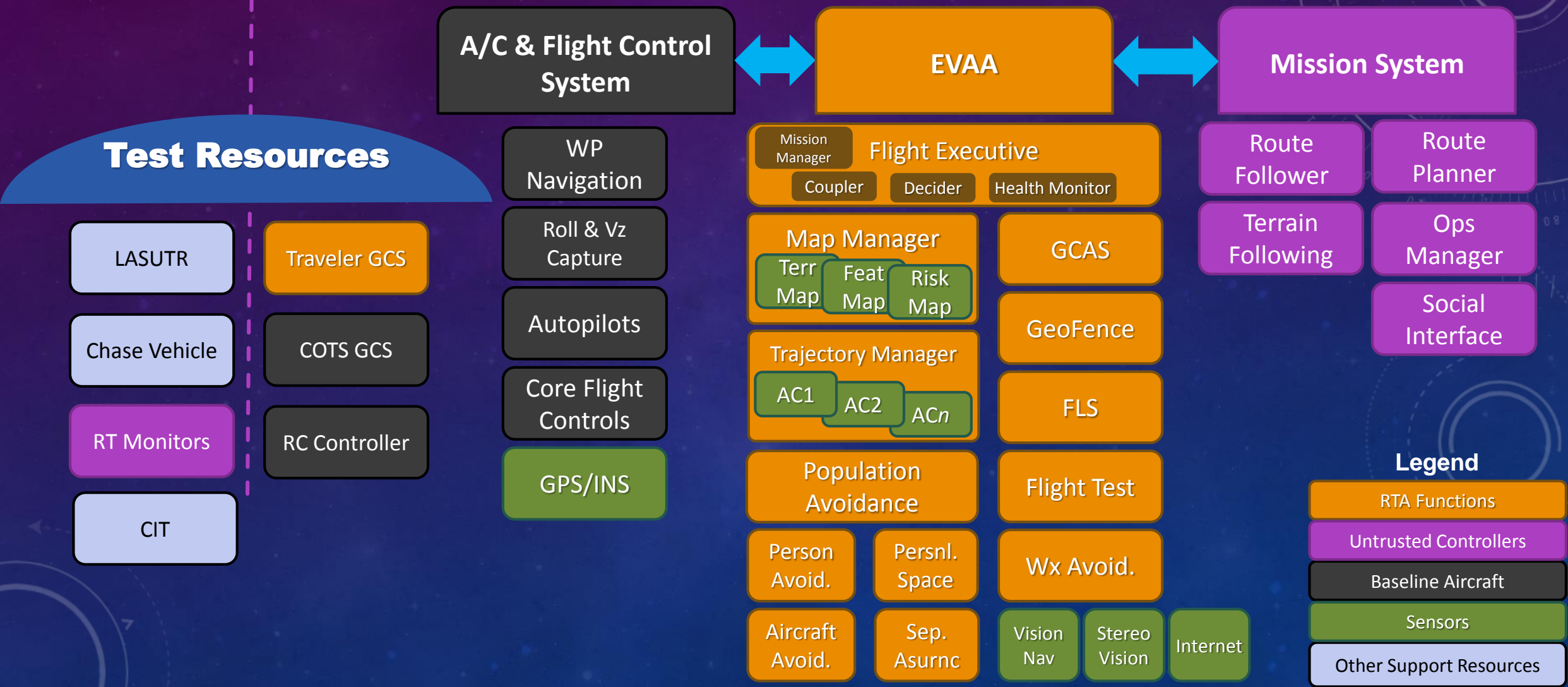
Phase 1
Integrated Testing

Traveler System



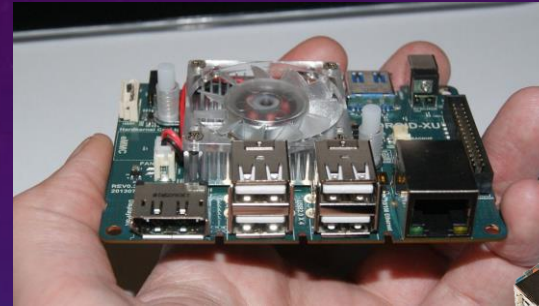
Phase 2

Traveler System



EVAA Phase 2 Aircraft

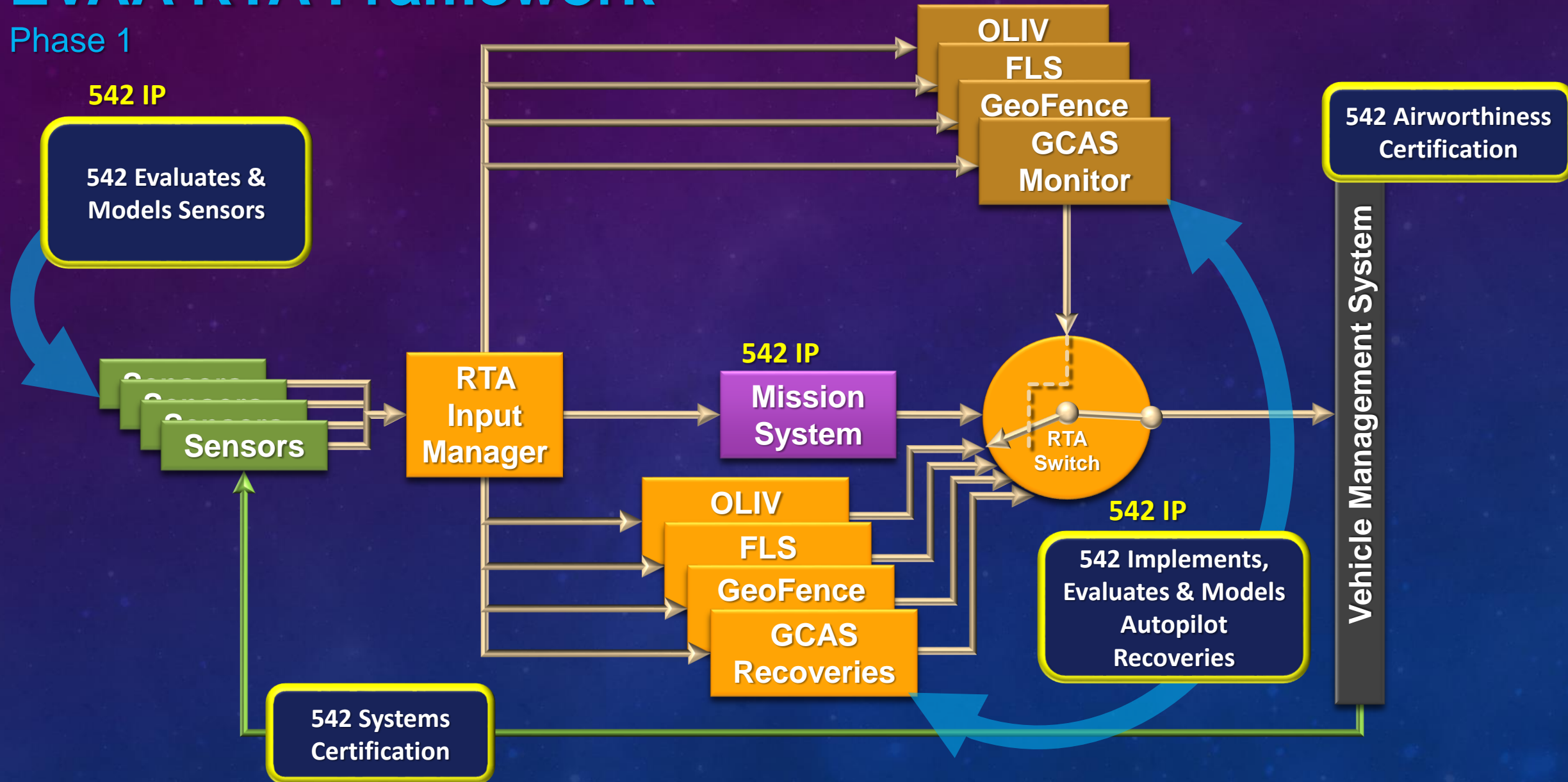
- VTOL & Forward Flight Capable
- Payload Capacity for Sensors & EVAA
 - EVAA Processors, Wiring & Interfaces
 - 1 - oDroid XU4 0.16 lbs.
 - 2 – Adrino Processors
 - Speaker
 - Lights 0.35 lbs.
 - Sensors
 - 4 - Stereo-Vision Camera Pairs and Processors
 - ADS-B 0.07 lbs.
 - UTM Wireless Interface
 - Flight Test TSPI, etc. 0.57 lbs.
- 50 to 75 MPH Flight Speed
- 50 to 75 Mile Range
- Easy Break-Down & Assembly for Transportation to and from Test Sites



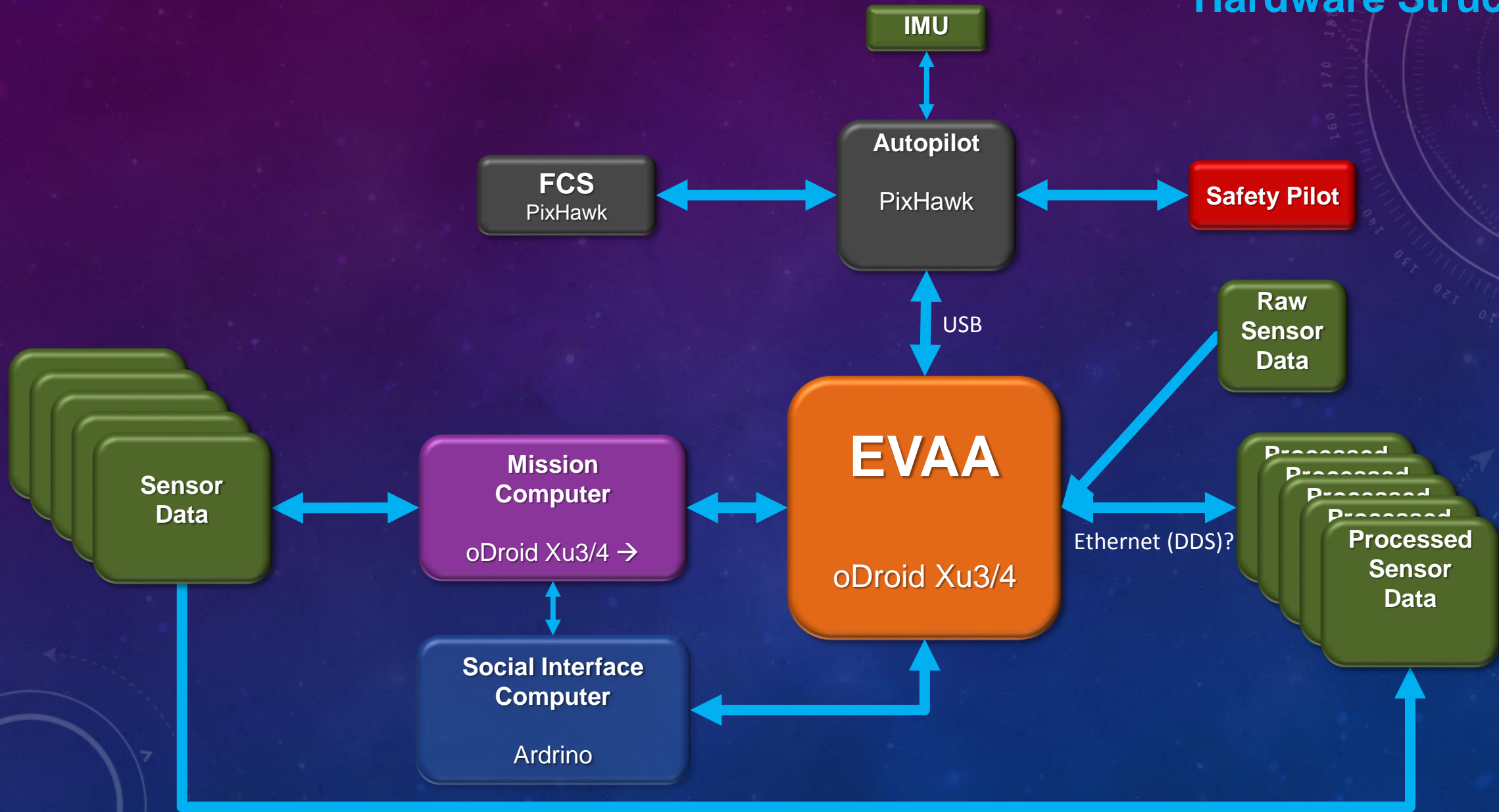
EVAA RTA Framework

Phase 1

RTA Framework



Expandable Variable-Autonomy Architecture (EVAA) Hardware Structure



Functional Block Diagram

